# MATTERS ARISING

## Peridotite xenoliths in basalts and mantle dynamics

BASU[1] has described jointed and angular xenoliths of mantle peridotite in alkali basalts from California. He considers their morphology to be due to brittle fracture at the site where the xenoliths were incorporated into the rising magma, and thus to be representative of dynamic conditions in the upper mantle. I believe this conclusion to be unwarranted, for the following reasons.

Mitchell *et al.*[2] have modelled the thermal response of xenoliths to enclosing magma, and have demonstrated that blocks of the size described by Basu are heated to the temperature of their surroundings in a matter of hours. Exceptionally high magma ascent rates are, therefore, required if xenoliths are to be brought from the mantle to the surface unaffected by incorporation into basalt.

Basu assumed a newtonian rheology for alkali basalt magma when calculating nodule settling rates. This assumption is invalid as magmas commonly possess a yield strength at subliquidus temperatures. Sparks *et al.*[3] have considered the effect of non-newtonian rheology on the transport of xenoliths by magmas. They conclude that blocks of the sizes observed have zero settling velocity in the majority of magmas. Thus, Basu's calculation of magma ascent rate cannot be justified.

In xenolith suites where a range of rock types is represented, fragment angularity is highly variable and unrelated to mineralogy or depth of origin.

Non-newtonian magma rheology favours xenolith transport by slow, rather than rapid, ascent of magma[3]. Thus xenoliths are likely to have been in a state of internal chemical and mechanical disequilibrium for a considerable time before their arrival at the surface. Brittle failure occurs as a response to changing conditions after incorporation of a xenolith into rising magma. Angular ultrabasic blocks from La Palma, Canary Islands, show such clear evidence of disequilibrium as partial melting induced by heating by the host magma (my unpublished data). Ultrabasic xenoliths in basalts should be regarded as unreliable guides to dynamic conditions in the mantle.

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BASU REPLIES—Central to Wolff's criticism is the conclusion by Sparks *et al*[1] that the abundance of ultramafic xenoliths in alkalic basalts is due to the slow rates of ascent of such magmas from mantle depths. Using thermal diffusivity arguments based on such measurements in olivines, Wolff also suggests that blocks of ultramafic xenoliths will attain thermal equilibrium with their enclosing basalts in a matter of hours.

The xenoliths under discussion and other associated xenoliths in the same lava flow in San Quintin volcanic field show evidence of strong plastic deformation. My conclusion that these xenoliths could not have spent longer than a few hours in the ascending magmas is also compatible with conclusions based on recovery kinetics in deformed olivines[2,3]. The deformed porphyroclasts of olivine in these xenoliths are expected to be completely recrystallized in a few hours due to the relatively fast kinetics of grain growth in conditions of high temperature thermal equilibration with the host lava. The survival of the plastically deformed porphyroclasts of olivine attests to their very short-lived association with the host basalt. Thus, Wolff's contention that "brittle failure occurs as a response to (slowly) changing conditions after incorporation of a xenolith into rising magma" is untenable.

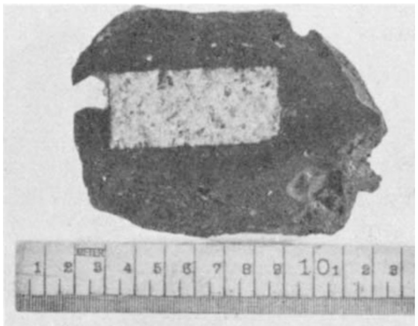

**Fig. 1** Perfectly rectangular block of ultramafic xenolith in alkalic lava from the Mt Schank volcano in SE Victoria, Australia. (Photograph courtesy of Dr Alan Moore, University of Cape Town, South Africa.)

Wolff favours a non-newtonian basalt rheology for slow xenolith transport and suggests that the "xenoliths are likely to have been in a state of internal chemical and mechanical disequilibrium for a considerable time before their arrival at the surface." Figure 1 shows an almost perfect rectangular slab of an ultramafic xenolith surrounded on all sides by the alkalic vesicular lava from the Mt Schank volcano in SE Victoria, Australia. Could the orthogonal joint planes in Fig. 1 have formed by brittle failure as a response to changing conditions after incorporation of this xenolith by the host magma? Or did these joint planes form before the xenolith was included in the magma? The xenolith in Fig. 1 shows typical porphyroclastic texture and evidence of plastic deformation. This evidence alone, because of the nature of the recovery kinetics as discussed above, refutes Wolff's central thesis that the joint planes formed after incorporation of the xenolith by the magma.

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## Late Eocene rings around the Earth?

THE suggestion by O'Keefe[1] that the "terminal Eocene event" was caused by rings of tektite material encircling the Earth deserves criticism. O'Keefe assumes tektites to be of cosmic origin and cites his book[2] in which it is suggested that tektites originate from lunar volcanoes. This assumption is unwarranted and contrary to the numerous existing data[3–6]. Four specific difficulties are obvious. First, there are no known lunar rocks that are chemically suitable parent materials for tektites or which even appear possibly related to objects of this composition[3–7]. Second, there are no known lunar rocks of the correct age to satisfy O'Keefe's hypothesis. This is not trivial, as the most recent lunar rocks that have been dated are two orders of magnitude older than those required by O'Keefe. Third, we do not find that the North American tektites fell or were initially deposited throughout a sedimentary rock column of a few million years. Fourth, we have not found even a single tektite with a measurable cosmic ray exposure age, and the detection limits are well below the lifetime of the rings as deduced by O'Keefe.

What then caused the "terminal Eocene event?" I do not propose to answer that question. However, I do suggest that those who are interested in this problem consider the great volume of volcanic ash, air-fall tuff and bentonite (altered volcanic ash and tuff) that occurs in the late Eocene

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